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Unmanned Aerial Vehicles for Rapid Environmental Assessment and Mine Countermeasures

Manuel de Sousa

Maritime Operations Division
Defence Science and Technology Organisation

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ABSTRACT

This reports looks at some of the UAV options and sensors which might be of interest in conducting Rapid Environmental Assessment (REA) operations or Mine Counter Measures (MCM), and issues governing their use on small naval platforms.

Deployment and recovery of UAVs plus the integration of vehicle logistical support and sensor data analysis are more problematic in littoral warfare operations. Some of the traditional airborne electro-optic and electro-magnetic sensors are now capable of being miniaturised to sizes and payloads within UAV limits, but the number and type of sensors chosen for REA can greatly influence the design and overall size of a UAV.

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DSTO Defence Science and Technology Organisation
PO Box 1500
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Telephone: (08) 8259 5555
Fax: (08) 8259 6567

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Executive Summary

Unmanned aerial vehicles (UAVs) are becoming increasingly accepted in all facets of military operations so it is not surprising that they should be looked at in the context of littoral operations, where the pre-engagement focus is on environmental assessment and to a lesser extent mine counter measures. Some of the traditional airborne electro-optic and electro-magnetic sensors are now capable of being miniaturised to sizes and payloads within man-portable UAV limits.

This reports looks at some of the UAV options and sensors which might be of interest in conducting rapid environmental assessment (REA) operations or mine counter measures (MCM), and issues governing their use on small naval platforms.

Contents

1. Introduction

This report is not an extensive study of current unmanned aerial vehicles (UAVs) and sensors. It focuses on types of unmanned aerial vehicles and sensors that might be of interest for rapid environmental assessment (REA) or mine counter measures (MCM) in littoral warfare operations. The number and type of sensors chosen for REA can greatly influence the design and size of a UAV, which will have to be accommodated into existing or projected maritime platforms. Vehicle logistical support and sensor data analysis also have to be integrated into littoral fleet operations.

2. Classification of UAVs

Unmanned Aerial vehicles (UAVs) can be characterised and classified in different ways, such as flight altitude, endurance, observability, size, etc. Some attempts have been made to group them into Tiers [1], as shown in Table 1, but there is such a variety of vehicles that there are always some that overlap the categories.
The UAV Forum has descriptors for UAVs based on flight envelope, size/weight and function [2].

Table 1. UAV Tier Classification and Characteristics [1]

Category	Designation	Max Alt	Radius	Speed	Endurance	Example
Tier I	Interim-Medium Altitude, Endurance	Up to 15,000 ft	Up to 250 km	60-100 kn	5–24 hrs	Pioneer; Searcher
Tier II	Medium Altitude, Endurance	3,000 ft to 25,000 ft	900 km	70 kn cruise	More than 24 hrs	Predator (used in Bosnia)
Tier II Plus	High Altitude, Endurance	65,000 ft max	Up to 5,000 km	350 kts cruise	Up to 42 hrs	Global Hawk
Tier III Minus	Low Observable - High Altitude, Endurance	45,000 ft to 65,000 ft	800 km	300 kn cruise	Up to 12 hrs	Darkstar

The term 'Endurance UAV' is reserved for vehicles capable of extended flight of 24 hrs or greater, and can be further broken down into Operative (medium altitude) and Strategic (high altitude). These are usually large UAVs requiring land-based runways with the largest payload capacity.

The term 'Tactical' is sometimes used for all air vehicles between 20 and 500 kg.

Micro Air Vehicles (MAVs) are defined as having no dimension larger than 15 cm. With indicative characteristics like 50 g weight, endurance of 30-60 minutes and range of 3-10 km, the small mass would limit payloads to items like simple cameras and communication relay devices. They would be ineffective as REA platforms because optical sensors of this size and mass do not have sufficient resolution and are incapable of penetrating the water column. Also vehicles of this size and mass are limited to operating in light wind conditions.

Man Portable UAVs are light enough to be backpacked by an individual and launched by hand throwing or a sling shot mechanism. Typically they would weigh less than 5 kg and would have sensors more suited to intelligence and reconnaissance activities. Many of these would be electrically powered to avoid detection. The range of sensors for REA activities on these vehicles would be minimal, e.g. small photographic, IR.

Vertical Takeoff & Landing (VTOL) are typically rotary wing but could include tail sitting UAVs and tilt wing configurations of winged UAVs that can initially take off vertically. Because of the reduced space requirements for deployment and recovery and larger payload capabilities, these vehicles look to be the most promising alternative for smaller maritime platforms (Figures 1-5).

Figure 1. CL-327 Guardian Bombardier Services Corp

Figure 2. Heliwing The Boeing Co. Defence and Space Group

Figure 1. Vigilante 502, Science Applications International Corp

Figure 4. Eagle Eye TR911B, Bell Helicopter Textron, Inc

Figure 5. Fire Scout, Northrop Grumman

3. Rapid Environmental Assessment (REA) parameters

Rapid environmental assessment parameters fall into three areas of interest representing the air column, sea/land surface and sub surface, of which the underwater environment dominates.

Because a UAV flies through the air column, parameters such as air pressure, temperature and humidity are easily measured from relatively small sensors (less than 1 cm). Wind conditions can also be assessed directly with sensors or deduced from the flight profile of the UAV.

Subject to visibility conditions, parameters like surface swell, wave height, and land and beach topography can be measured from varying altitudes and with varying resolutions with look-down sensors. Depending on the type of technology used and their sophistication, these sensors can vary in weight from miniature camera packages (less than 1 kg) to hundreds of kilograms. These sensors don't generally dictate the payload requirements of a UAV. A compromise solution is usually to find the smallest sensor with the necessary resolution to do the job that meets the payload capability of the UAV.

Determining parameters like bathymetry and seabed properties, as well as underwater object identification and buried object detection present the most challenging problems for aerial platform-based sensors. This is even more problematic if the aerial platform is small and unmanned. For example, sensors for bathymetry, even when miniaturised down from manned fixed wing equivalents, are unlikely to weigh less than 10 kg, but with current technology are not less than 30 kg. For laser systems the limiting factor is the mass of the optical components and power supplies (typically greater than 10 kg [5]), while for electromagnetic sensors it is the size of the coil (more than 2 m diameter [6]). UAVs fitted with electromagnetic bathymetry sensors would need to fly at low altitudes (typically 30 m or less) in order to maximise sensitivity and are thus more prone to detection. The need for sensors that can penetrate the water column has a large influence on the size of the UAV payload, its mode of operation and its energy consumption.

4. Sensor capabilities

Small Micro-Electro Mechanical Systems (MEMS) sensors are available that are capable of measuring atmospheric properties such as temperature, pressure and humidity. An indication of their size and weight can be inferred from publications describing them as "sensors on a chip". They are the sensors with the least impact on any UAV payload limits.

LIDAR (Light Detection and Ranging) sensors can be used for bathymetry, and shoreline and land topography. Since it is an active system it can be used day or night, but does not work well in fog, over surface ice or mirror flat ocean surfaces because of enhanced surface light reflectance. It can measure coastal water depths to about 50 m (in the tropics) and

with sufficient spot density can also locate objects large (e.g. manned submersibles) and small (e.g. sea mines) on the ocean floor. These sensors are already established for manned fixed wing aircraft and helicopters and would need to be miniaturised for application to UAVs with a probable payload in the vicinity of 30 kg [7].

Photogrammetry, video, IR and thermal imaging can be used for extracting sea surface parameters, beach/land topography and for the detection of animals and vehicles. These are usually the primary tactical sensors on UAVs and are well established and readily available. Visible light (Electro Optic) imaging under optimal conditions yields the highest quality imagery in terms of resolution and interpretation quality. Its operation is limited to daytime clear weather conditions unlike IR sensors, which are able to penetrate atmospheric haze more readily than EO sensors and can operate day and night. Since IR sensors operate on thermal effects they are capable of discriminating between operating and non-operating vehicles, real facilities and decoys. Thermal imaging, however, cannot distinguish fine details and is not suitable for penetrating the water column.

Hyperspectral and multispectral sensors can penetrate the water column and on land can be used to detect vehicles under partial vegetation cover. Since imaging with these sensors is a passive technique depending on sunlight illumination, missions are limited to specific weather conditions and times of the day - conditions that generally favour the detection of the UAV. They are increasingly established as airborne and satellite sensors but not UAV sensors.

Synthetic aperture radar (SAR) is the most versatile of imaging sensors that can work day and night in all meteorological conditions. Radar wavelength allows imaging of the ground through cloud cover. Typically these sensors are about 100 kg and their range is dependent on the length and transmitting power of the antenna. Mini versions of SAR more suited to smaller UAVs are available (5 kg), with reduced ranges due to the smaller antenna lengths. This type of sensor is good for producing digital elevation models and for surface displacement monitoring, thereby enabling the measurement of environmental parameters like wave motion and wind conditions at sea level.

Airborne Electro-magnetic (AEM) sensor systems for mineral exploration mounted on both fixed wing aircraft and slung beneath helicopters are well developed and have also been trialled for bathymetry with some success. They typically weigh 100 kg, and would need to be miniaturised and reduced in weight for incorporation into UAVs. Possibly a weight reduction would lead to a sensor system of about 30 kg. The UAV would need to fly at low altitude to maximise sensitivity but is unaffected by turbid water and can give results to depths of about 80 m. With this sensor seabed composition information can also be extracted. The configuration and size of this type of sensor may dictate the design of the UAV so that it effectively looks more like a flying sensor than a conventional vehicle with payload (Figures 6 and 7).

Magnetometer and gradiometer sensors are not suitable for REA but have the capability of detecting submerged objects and land based metallic materials that might be either camouflaged or buried. It is yet to be determined whether they can pinpoint mine-sized objects underwater or buried in the seabed. Over land their effectiveness in finding

concealed vehicles or buried armament caches is also untested. In urban areas they may provide a means to localise buildings used for concealing military supplies.

Figure 6. Hoistem system originally developed by Normandy Mining Ltd, now Newmount Mining Pty Ltd

Figure 7. GEOTEM airborne electromagnetic time domain system, trademark of Fugro Airborne systems

5. Deployment platforms and recovery

Endurance UAVs with their relatively large payloads have the capability of measuring a large number of environmental parameters including bathymetry utilising either electro-optic or AEM sensors (10-50 kg). Requiring land based runways they are only limited by their range and endurance. They could conceivably be used for expeditionary operations if their endurance enabled them to be effective over the area of interest before returning to base. In this case expediency would have to outweigh risk to the vehicle since effective sensor system performance like aerial EM bathymetry may require flying at low altitude.

Tactical fixed wing UAVs are more suited to deployment from maritime platforms. Larger vehicles could take off and land on a mobile flight deck. The use of capture devices like nets would probably be essential since it removes the requirement for braking systems on the vehicle. When these vehicles are used over land, systems like parachutes and air bag cushioning can be very effective for recovery. At sea there is a high probability that these devices will not avoid a water recovery. The use of deliberate water recovery means extra cost associated with engineering watertight onboard systems, engine, servos and also waterproofing REA sensors. This would also add weight to the vehicle thus reducing payload. Immersing the engine would lead to greater turn around time between missions since it requires flushing out of salt water and drying before next takeoff, or complete engine replacement.

Smaller vehicles can take off with the aid of a catapult. Vehicles on rail assemblies can be accelerated using bungee-cords, pneumatic power, air motors or a combination of hydraulic/pneumatic power. Alternatively, rocket assisted take off (RATO) is also a common method of accelerating military UAVs. This initial acceleration is required to achieve the minimum speed for aerodynamic lift and control effectiveness. Ships with areas the size of helipads can recover these UAVs with capture schemes such as flying them into a soft net. A net-like capture device provides some restraining capability that would be useful in adverse sea state conditions. Other schemes like deploying a parasail for a glide landing or a mid-air recovery using a manned vehicle have also been proposed. These type of schemes probably introduce more complexity than is warranted for an already difficult environment to work in. Using a seaplane-like variant for a water landing is possible. This would make the vehicle more expensive and logistically difficult to recover at night or in bad sea conditions. It may, however, be viable for very small platforms where there is no space to set up a capture device or for special operations (Figure 8).

Figure 8. Neptune Air Vehicle, DRS Unmanned Technologies

Vertical Take Off and Landing UAVs can either be winged vehicles or Rotorcraft (e.g. helicopter). The benefit of these UAVs is the relatively small deck area required for take off and landing. Winged variants have mechanisms for tilting wings/propellers on take off or are tail sitters allowing them to stand on end for take off and landings. In terms of payload tilt wing craft or tail sitters are not more capable than conventional runway fixed wing variants and use more fuel during take off and landing.

Rotary wing UAVs have great versatility in terms of payload capacity and the ability to hover or fly at slow speeds over areas of interest. The larger bathymetric sensor systems could be integrated into these vehicles and operate from small helipad deck spaces. The one area of concern would be the scenario where take off took place in acceptable conditions only to find weather and sea state conditions had deteriorated significantly by end of mission. Landing becomes an issue since it places personnel and the vehicle at risk, especially just after touchdown, while the rotors are still functioning. It would be beneficial to investigate reeling down or automatic lock down systems as part of an acquisition for this type of UAV.

6. Mine Counter Measures

Some of the sensors required for environmental assessment also have the capability of detecting submerged objects of interest. Classification of an object as a mine followed by neutralisation is normally carried out by a diver or an Underwater Vehicle (either autonomous or remotely piloted). Having some of this capability in a UAV offers significant advantages.

An Unmanned Aerial Vehicle can survey more area in less time than an Autonomous Underwater Vehicle (AUV). An AUV is not likely to survey at speeds exceeding 5 m/s, while even small UAVs can average 30 to 50 m/s.

Although fixed wing UAVs may play a role in localising objects they are unlikely to be very effective in active mine countermeasures. Aerial platforms with hover capabilities would be more useful in this role, with options such as firing super cavitating projectiles into shallow water (10 m), or launching smaller expendable mine neutralising devices (possibly an Unmanned Underwater Vehicle (UUV), such as a one shot mine destructor).

As a localisation vehicle a UAV may significantly enhance the endurance of an AUV. The AUV would no longer need to conduct a complete underwater area survey using up valuable battery power if it can be networked to a UAV that has already pinpointed areas of interest.

7. Surveillance and intelligence

UAVs with Electro-optic and IR sensors are already well established as battlefield equipment for intelligence gathering, surveillance, target acquisition and damage assessment, so it would make sense that a UAV equipped with such sensors for REA activities would not be overlooked for battlefield support as well. Although not strictly tailored for battlefield support, REA platforms would have electro-optic, IR and possibly a combination of other sensors which could provide valuable information to a military commander in the absence of a more suitable platform. An example of this would be a UAV with thermal imaging sensors gathering sea surface parameters at night would also be able to pinpoint any surface craft in its flight path.

Generally the resolution required on REA sensors is not as high as on surveillance platforms which need sufficient detail for target identification, whereas a REA platform usually only needs to sample data over a much broader area.

A role not generally associated with environmental assessment is the detection of man made environmental hazards such as chemical, nuclear and biological agents. Concurrent sampling for this type of hazard is not unreasonable for a UAV performing REA surveys since miniaturised chemical sensors have been developed (e.g. Chemsonde).

8. Manning, servicing, overhaul, turnover, field repairs

When operating as part of an expeditionary force, the utilisation of UAVs requires dedicated logistics. Operating and maintaining them requires dedicated ground crews and maintenance backup. In this scenario it is not possible to send vehicles back to the manufacturer for overhaul, repairs or minor maintenance and expect them back in time for the next mission. Turnaround times between flights can be expected to be short (hours). An expensive option is to carry lots of vehicles and put aside any damaged or malfunctioning units.

An experienced logistics and maintenance team should be able to effect minor structural repairs, overhaul engines in the field, carry spares of critical avionics parts and sensors, and generally scavenge components from unserviceable vehicles. This capability is essential in order to maximise operational success especially in prolonged deployments. In hostile environments higher vehicle attrition rates are compensated by their relatively low cost, and is consistent with current military doctrine of taking the man out of the loop.

UAV vehicle power can be delivered by jet, 2-stroke, 4-stroke or diesel engines in combination with electric battery storage systems. Some smaller UAVs can be totally electric. The storage and handling of fuel and batteries has to be considered in the context

of ship operations. If a RATO system is used for launch, then the handling and storage of rocket boosters also needs to be addressed.

Flight control systems need to be tested and mission parameters need to be programmed into the vehicle prior to takeoff. The collected environmental data whether it is obtained real time or downloaded post mission needs to be processed and analysed. The analysed data needs to be assessed in its entirety, interpreted and presented in a form that a military commander can formulate operational decisions. This is a process that requires trained personnel with a mixture of autonomous systems, meteorology, bathymetry, topography and possibly mine warfare skills. The relaying of information to and from operational headquarters to the field is probably best served by having an REA specialist as part of the headquarters team.

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Manuel De Sousa

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